

In a most preferred embodiment, the metal alloy of the airfoil is a titanium alloy foil produced by superplastic forming. A Ti-6Al-4V titanium alloy is selected because of its high strength-to weight ratio. This metal may advantageously be superplastically formed as is well-known to those skilled in the art at temperatures of about 1600° by using a pressurized inert gas to form the material to the desired shape and thickness against a mandrel using standard superplastic forming techniques. The final desired thickness is about 0.005-0.015 inches.

The energy-absorbing elastomeric layer 30 may be a modified adhesive film, an adhesive film having a thermoplastic carrier, or a polyurethane film coated with an adhesive layer. A further distinguishing characteristic of the elastomeric layer, in addition to being energy-absorbing, is its ability to bond with the metallic foil.

When the elastomeric layer 30 is a modified adhesive film, preferred elastomers are epoxy resins having low flow characteristics such as FM-300I obtainable from American Cyanamid.

When the elastomeric layer 30 is an adhesive film having a thermoplastic layer carrier, preferred elastomers are HXT-440, or a bis-maleimide such as HXT-441 both obtainable from American Cyanamid.

When the elastomeric layer is a polyurethane film coated with an adhesive layer, the total thickness of the polyurethane-adhesive coated film is approximately 0.003-0.015 inches. Referring now to FIG. 2, a cross section of a polyurethane film 36 coated on each side with an adhesive layer 32 forming elastomeric layer 30 is shown. A polyurethane film having adhesive layers and of the required thickness may be obtained from the 3-M Company.

The laminated airfoil 10 is formed by taking the metallic foil, and if necessary, pre-shaping the metallic foil into a predetermined shape. The metallic foil is then accurately trimmed to a predetermined size using standard trimming techniques. The metallic foil 28 and the heat-flowable energy-absorbing elastomeric layer 30 are then assembled into a die assembly in alternating layers. The die assembly is a conventional mold tool assembly in which the cavity of the die has the shape of the desired end product, in this case a laminated airfoil. The metallic foil 28 and the heat flowable elastomeric layer 30 are alternately layered into the die cavity, with the metallic foil forming the first layer and the last layer in the die cavity, so that the outer surfaces of the airfoil are metallic. Optionally, a leading edge sheath made from a metallic material, preferably a titanium alloy such as Ti-6Al-4V, may be assembled into the die assembly. This die assembly is then pressed while applying sufficient heat and pressure to flow the elastomeric layer thereby simultaneously bonding the elastomeric layer to the foil and the optional leading edge sheath and curing the ply assembly into a cured airfoil having net shape or near net shape.

In a preferred embodiment, titanium alloy foil, such as Ti-6Al-4V in accordance with AMS-4911 having a nominal composition in weight percent of about 5.5 to 6.75% Al, 3.5 to 4.5% V, 0.30% Fe Max., 0.20% O Max., 0.08% C Max., 0.05% N Max., 0.015% H Max., 0.005% Y Max. and the balance Ti and incidental impurities, with no more than 0.5% incidental impurities and an elastomeric layer 30 of polyurethane film 36 and coated on either side with about 0.0025 inches of an adhesive film 32 such as AF163-2 obtainable from 3-M Company are placed in a die assembly in the manner

described above and heated at a temperature of about 230°-260° F. and to a pressure of about 50-150 psi for about two hours at temperature to form the near net shape airfoil.

The airfoil is then removed from the die assembly and trimmed if necessary. As depicted in FIG. 1, apertures 22 are drilled in the dovetail root flank surfaces 24 and adhesive-coated high strength metal members 26 are inserted into the apertures. These members provide additional strength to the airfoil. The additional strength is required in order for the dovetail to carry the compressive loads typically found in this portion of the blade. A metal sheath 20, preferably made from the same alloy as the metallic foil in the blade, in the preferred embodiment titanium alloy Ti-6Al-4V, is then applied to the leading edge 16 of the blade with an adhesive, preferably the same adhesive or material as used in the elastomeric layer. Optionally, the adhesive-coated metal sheath may be applied to the airfoil leading edge after assembly of the laminated airfoil preform assembly, but prior to insertion of the assembly into the die assembly, thus permitting the leading edge to be co-cured with the airfoil.

In a preferred embodiment of the present invention, the high strength metal members 26 disposed in each dovetail root section aperture 22 are titanium alloy pins, preferably Ti-6Al-4V. These pins are coated with an adhesive usually of the same type used in the elastomeric layer. These adhesives must be bondable to the metal of the pin and to the composite layers comprising the root section aperture 22.

In an alternate embodiment of the present invention, an airfoil of the type previously described is made by alternating layers of a metallic foil 28 and a polymeric composite layer thereby forming a laminated composite airfoil. In this embodiment, the polymeric composite layer is utilized in the same manner as the previously described elastomeric layer 30. The metallic foil once again forms the first and last layer assembled into the die so that the outer surfaces of the airfoil are metal. Titanium alloy pins coated with an adhesive capable of bonding to the alloy and the laminated-composite are disposed in each dovetail root section aperture 22. Furthermore, the minimum cure temperature capability of the adhesive must be approximately the same as the cure temperature of the laminated composite. Finally, the adhesive must be chemically compatible with the laminated composite comprising the blade. Adhesives which may be used include AF191 or AF163-2 obtainable from 3-M Company, FM238 obtainable from American Cyanamid or PL777 obtainable from B. F. Goodrich. After application of the adhesive, the pins are assembled through the dovetail root apertures.

In a preferred embodiment, the polymeric composite layer is a fiber embedded in a flowable resin based matrix forming a lamina. Any polymeric composite layer having a high strength-to-weight ratio and having a resin capable of bonding to metal is acceptable. In a most preferred embodiment of the present invention, the reinforcement is a 12 K filament tow of an intermediate modulus carbon fiber having an individual fiber cross-sectional thickness of about 5 microns. The flowable resin based matrix is selected from the group consisting of epoxy, BMI, and polycyanate. Preferred are F3900 or 8551-7 which are toughened epoxies. Thin layers of uncured polymeric composite material having thicknesses of about 0.005-0.006 inches are commercially available and may be obtained from Hexcel Corp.